Chapter 3
Watershed–Based Zoning

Introduction

The many independent lines of research reviewed in the last chapter converge on a common conclusion—that it is extremely difficult to maintain predevelopment stream quality after subwatershed impervious cover exceeds 10 to 15%. The same research also suggests that other apparent stream degradation thresholds exist that are closely related to impervious cover as well. This chapter explores the possible implications that these relationships can have for watershed planning, and is organized as follows.

The first section examines why conventional zoning techniques has limited value in preventing stream degradation. Next, a common terminology is presented to clarify key watershed management units. A simple scheme is then developed to classify urban stream quality. Streams are classified as either sensitive, degrading, or non–supporting, depending on the degree of impervious cover present in their subwatershed. The three subwatershed classifications form the basic framework for the watershed–based zoning process. Impervious cover limits and other unique stream management strategies are then tailored for each subwatershed to achieve or maintain the predicted level of future stream quality. Lastly, guidance is provided on how local governments can institute watershed–based zoning in their land planning efforts.

Impervious Cover and Conventional Zoning

Before advancing the concept of watershed–based zoning, it is necessary to understand why conventional zoning methods cannot adequately protect urban streams from degradation.

To begin with, conventional zoning uses some measure of population density as its main currency. For example, most residential zones are defined by the maximum number of *dwelling units* allowed per acre. Once this population density is set, it is a simple matter to multiply the density by the developed area and simple capacity factors to determine future infrastructure needs. This technique enables a community to forecast capacity needed for wastewater treatment, water supply, schools and roads for its future residents. Population density, however, is an indirect and relatively imprecise measure for forecasting the future quality of streams. The primary reason is that population density and impervious cover are only loosely related.

The lack of a tight relationship is due to the fact that impervious cover is found in two forms—rooftops and transport (i.e., roads, parking lots, driveways and sidewalks). In most suburban development, the transport form dominates over the rooftop form. Conventional zoning, however, only regulates the maximum density of rooftop impervious cover (i.e., the number of possible dwelling units on a site), and only marginally predicts the generation of transport–related impervious cover. The amount of transport–related impervious cover at a site depends on a unique combination of topography, site layout, street pattern, local design standards, parking lanes and driveway lengths. As a consequence, two sites that are zoned for the same number of dwelling units can have widely different levels of total impervious cover.

Watershed Protection Strategies Under Conventional Zoning

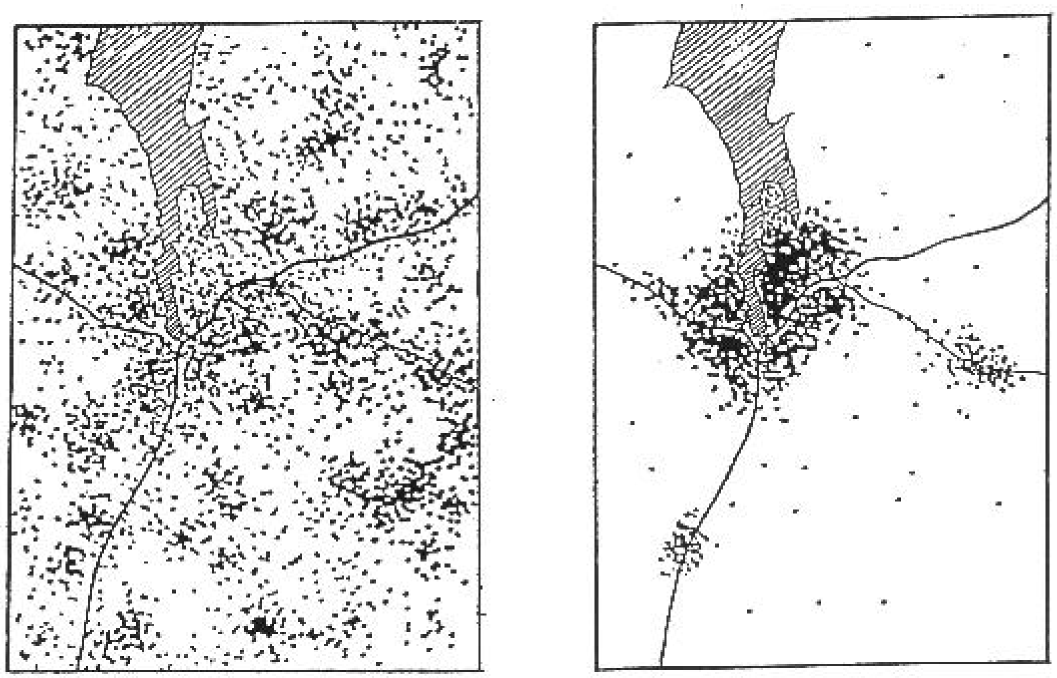
Traditionally, communities have employed two strategies to mitigate the impact of development on sensitive watersheds: dispersed development and best management practices. The first option is termed *large lot zoning*, which involves a widespread reduction in the number of dwelling units allowed per acre. For example, maximum allowable density might be decreased from 2 dwelling units/acre to one dwelling unit per one, two or even five acres. The larger lots are expected to spread out the impact of development, and produce less stormwater runoff and pollutant washoff. Communities that have used large–lot zoning to protect sensitive watersheds, however, have found it to be a somewhat clumsy tool.

To begin with, while large lot zoning will certainly reduce rooftop impervious cover in a watershed, it does not necessarily follow that the amount of transport–related impervious cover needed will decline. In fact, large lot zoning often increases the total amount of impervious created for each dwelling unit. This is caused by the longer road network needed to connect the larger lots. Second, even if large lot zoning had no effect on impervious cover, it still would contribute to regional sprawl. The same number of dwelling units must be spread over a much wider geographic area than they otherwise would have been, thereby subjecting more subwatersheds to potential degradation (Fig. 13). Paradoxically, the best way to minimize the creation of impervious cover at the regional scale is to concentrate as much of it as possible in high density clusters in some subwatersheds (high levels of impervious cover—25% to 100%), so as to prevent other subwatersheds from exceeding the 10% impervious threshold. Watershed managers are faced with the dilemma that by trying to protect one stream, it may be necessary to degrade another.

Third, it is much more expensive to construct and provide public services on large residential lots, compared to smaller ones. In particular, many communities find that on–site septic systems are the only economical form of sewage disposal at this scale, and these systems have the potential to create future water quality problems (Ohrel 1995). Last, and most importantly, large lot zoning does not always guarantee that the total impervious cover in a watershed will not exceed the stream degradation threshold of 10 to 15%).

The second strategy depends on the widespread construction of stormwater BMPs to mitigate the impact of impervious cover. Recent research and local experience indicate

FIGURE 13: DISPERSED VERSUS CONCENTRATED DEVELOPMENT AT THE REGIONAL SCALE



Two views of growth are shown in this graphic from Wells 1994. The first shows dispersed development in the form of low density sprawl, while in the second, new development is concentrated in existing growth centers. At a regional level, the second growth option produces less impervious cover.

that exclusive reliance on BMPs may be a questionable watershed protection strategy.

While performance monitoring has documented that many stormwater BMPs can achieve high pollutant removal rates, their performance and longevity in the field are often sharply reduced due to poor design, construction or a lack of maintenance (Schueler et al. 1992). Stormwater pollutant exports will still exceed predevelopment levels even at moderate levels of impervious cover, despite widespread application of stormwater BMPs (see Chapter 2). In addition, few BMPs are able to replicate predevelopment hydrology and are not always effective in protecting downstream channels from erosion. Further, the cumulative benefit of widespread implementation of stormwater BMPs has yet to be conclusively demonstrated at the watershed scale (Claytor and Ohrel 1995). For all these reasons, communities should be cautious about relying solely on stormwater BMPs and large lot zoning to protect sensitive streams.

Watershed Geometry and Terminology

Although the watershed is gaining increasing acceptance as the most appropriate geographic unit for managing water resources, there is some confusion about what boundaries to use to define them. The standard definition of a watershed is rather slippery—it is defined as all the land area that contributes runoff, or drains, to a particular point along a waterway. As such, it is possible to define almost an infinite number of watershed boundaries, depending on what point is chosen as a reference. Therefore, scale is some importance when defining watershed boundaries for local planning.

To avoid confusion, the following practical terminology is offered to provide a common framework for watershed planning. Five basic watershed management units are recognized that have a unique physical and jurisdictional definition, as shown in Figure 14 and Table 6.

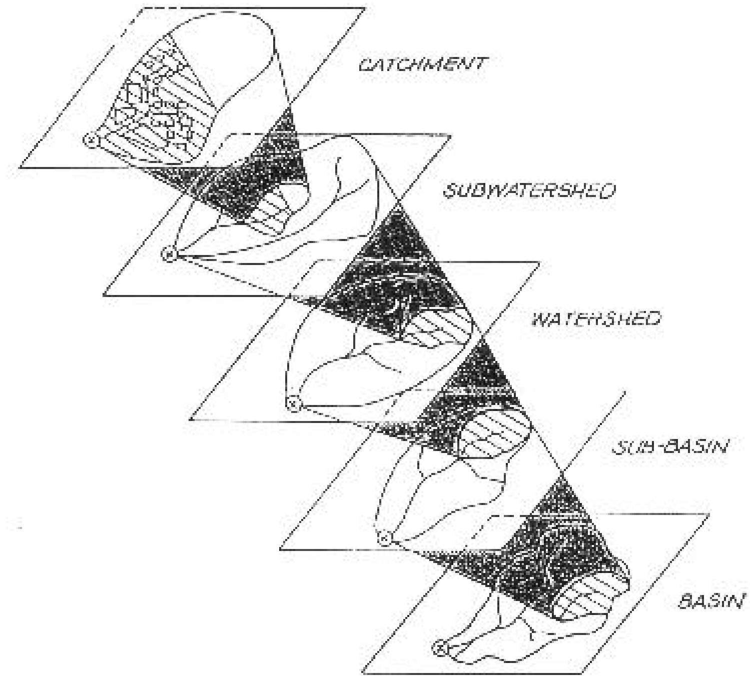
The smallest watershed management unit is termed a *catchment*, and is defined as the area that drains an individual development site to its first intersection with a stream (usually in the form of a pipe outfall). A catchment often includes off–site drainage above the development site, as long as it flows into the development site. Most catchments are quite small, ranging from a few acres up to several hundred acres in size. The management significance of the catchment lies in the fact that the quality and quantity of its runoff are entirely influenced by the development activity within it. Thus, a catchment is the primary focus for the planning and engineering of best management practices.

The next larger watershed management unit is called a *subwatershed*, whose boundaries include all the land area draining to the point where two second order streams combine together to form a third order stream. While the selection of this particular point appears somewhat arbitrary, it does provide a consistent and uniform basis for mapping the many small watersheds within a community. In most regions of the country, a subwatershed is a few square miles in area, and is drained by a creek or run that is several feet wide. Still, the limited stream network within a subwatershed is small enough that it is possible to characterize the impact of development on the streams at one or two sampling stations. From a management standpoint, the subwatershed is the primary element for urban stream classification, since the cumulative impact of development is best detected or forecasted at this scale, based on impervious cover.

The third largest watershed management unit is known simply as the *watershed*. It encompasses the drainage area of the larger streams that exit a community or municipality, and is composed of several subwatersheds. Depending on its political boundaries, a community may have several unique watersheds that may range in size from ten to a hundred square miles. The watershed is the primary unit for watershed–based zoning and land use planning as described later in this chapter. By this definition, the watershed is the largest drainage area that falls within a single local land use planning authority.

Clearly, important water resources extend far beyond the political boundaries of a local jurisdiction. These larger watershed management units are known as *subbasins*. The exact boundaries of a subbasin usually depends on the nature of the receiving water (usually a river reservoir or estuary and are set by the

FIGURE 14: RELATIONSHIP OF WATERSHED MANAGEMENT UNITS



Each of the five watershed management units represents a different scale for water resources planning. Note how each unit is "nested" within the next larger unit.

TABLE 6: CHARACTERISTICS OF FIVE WATERSHED MANAGEMENT UNITS

Watershed Management Unit	Typical Area (sq miles)	Influence of Impervious Cover	Primary Planning Authority	Management Focus
Catchment	0.05 to 0.50	very strong	Property owner Local	BMP and Site Design
Subwatershed	1 to 10	strong	Local government	Stream Classification & Management
Watershed	10 to 100	moderate	Local or Multi-local	Watershed-Based Zoning
Subbasin	100 to 1,000	weak	Local, Regional and State	Basin Planning
Basin	1,000 to 10,000	very weak	State, Multi-State, Federal	Basin Planning

appropriate state or regional water quality authority). In most cases, subbasins extend over several hundred square miles, and are a mosaic of many diverse land uses, including forest, agriculture, range and urban areas. Subbasin water quality is heavily influenced by both point and nonpoint sources of pollution, and the analysis of water quality problems and management strategies is necessarily more complex (often requiring extensive monitoring and modeling efforts). Because of their large size, the influence of impervious cover in subbasins is generally not that great in comparison to other land uses. Also, subbasins encompass so many political jurisdictions that they can only be effectively managed through a joint local/state water quality management process, as described in EPA (1993) and Craeger et al. (1995).

The largest watershed management unit is termed the *basin*, which drains to a major receiving water such as a large river, estuary or lake. Basin drainage areas typically exceed several thousand square miles. Consequently, the boundaries of a basin often include major portions of a single state or even a group of states (e.g, the Potomac River Basin or the Chesapeake Bay Basin).

It is clear from this context that the most useful watershed management unit for local land planning efforts is the subwatershed.

A Model for Classifying Urban Stream Quality

Impervious cover thresholds can be used to classify the potential quality of an urban stream. An urban stream classification scheme is outlined in Table 7. Under this scheme, an urban stream can fall into one of three

TABLE 7: A MODEL FOR CLASSIFYING HEADWATER URBAN STREAMS BASED ON ULTIMATE IMPERVIOUS COVER

Urban Stream Classification*	**SENSITIVE 0-10% Imperv.**	**DEGRADING 11-25% Imperv.**	**NON-SUPPORTING 26-100%Imperv.**
Channel Stability	Stable	Unstable	Highly Unstable
Water Quality	Good-Excellent	Fair-Good	Fair-Poor
Stream Biodiversity	Good-Excellent	Fair-Good	Poor
Resource Objective	Protect Biodiversity & Channel Stability	Maintain or restore key elements of stream quality	Minimize Downstream Pollutant Loads
Water Quality Objectives	sediment and temperature	nutrient and metal loads	bacteria

**Note: range of impervious cover used to classify urban streams may shift among ecoregions.*

management categories based on the amount of impervious cover found in its subwatershed.

1. Sensitive Subwatershed (1–10% Impervious cover)

2. Degrading Subwatershed (11–25% Impervious cover)

3. Non–supporting Subwatershed (26–100% Impervious cover)

Stream goals and protection strategies are different for each category, to reflect what is actually attainable, given the amount of impervious cover in the subwatershed. The most protected category is the *Sensitive Subwatersheds,* where the primary management goal is to maintain predevelopment stream quality. Streams in this category are expected to have stable channels, relatively good water quality, and good to excellent diversity of aquatic insects and fish. Stream protection strategies for sensitive subwatersheds primarily rely on watershed–wide and site limits on impervious cover, as well as careful selection of urban best management practices.

Degrading Subwatersheds exceed the impervious cover threshold and then streams can be expected to experience some degradation over time (i.e., less stable channels, declining water quality and biological diversity). As a result, some of the more sensitive aquatic organisms may disappear from the stream community of degrading subwatersheds (e.g, trout and stoneflies). Nevertheless, it is still possible to maintain many key stream characteristics. Consequently, degrading subwatersheds are managed under a more active stream protection strategy that relies on the widespread application of BMPs, buffers and other practices to limit or compensate for these.

The last category, *Non–supporting Subwatersheds,* includes urban subwatersheds that have been, or are projected to be, developed well beyond the impervious cover threshold. It is recognized that pre-development channel stability and water quality cannot be maintained in these streams, even if BMPs and/or retrofits are widely applied. Because of these changes, the expectation is that these streams will not support much aquatic life, and have low or poor diversity of fish and aquatic insects. The overriding stream protection objective for streams shifts to the removal of urban pollutants to protect downstream waters. Efforts to preserve or restore biological diversity are not completely abandoned in non–supporting streams. Some can be partially restored using stormwater retrofits and stream restoration techniques where these are physically or economically feasible (see Claytor 1995 for a methodology to determine subwatershed restoration potential). For most non–supporting subwatersheds, however, new development or redevelopment is actively encouraged.

Watershed–Based Zoning

The underlying premise of watershed–based zoning is that impervious cover, rather than population density, is a superior measure of growth impact. Based on this single watershed

TABLE 8: RECOMMENDED PROCESS TO INSTITUTE WATERSHED-BASED ZONING

Step	Task
1.	Conduct comprehensive stream inventory
2.	Refine/verify impervious cover/stream quality relationships
3.	Map existing and future impervious cover at subwatershed level
4.	Designate subwatersheds into stream quality categories, based on growth patterns and attainable stream quality
5.	Modify existing master plan to meet subwatershed targets
6.	Incorporate any management priorities derived from larger watershed planning efforts (i.e., watershed, sub-basin or basin plans)
7.	Adopt specific stream protection strategies for each subwatershed
8.	Implement long–term monitoring and enforcement program to provide management feedback

variable, it is possible to classify and manage streams within a community. The sequence of steps involved in watershed–based zoning are summarized in Table 8 and described below.

- A community undertakes a comprehensive physical, chemical and biological monitoring program to assess the current quality of its “stream inventory.” The sampling is used to identify sensitive stream systems, and to refine and verify local impervious cover/stream quality relationships.

- Existing impervious cover is measured and mapped at the subwatershed level. Projections of impervious cover due to future growth also made based on the build out of existing zoning.

- Each subwatershed is then designated into one of the three stream quality categories—sensitive, degrading or non–supporting—that reflect the level of stream quality attainable under existing environmental conditions and ultimate level of impervious cover (Fig. 15 and Table 9).

- A land use master plan is developed or revised to ensure that future growth (and impervious cover) is compatible with the designated stream classification for each subwatershed.

- Specific stream management strategies are then adopted for each subwatershed. The management strategies can include watershed or site limits on impervious cover, BMP selection criteria, stream buffers, land acquisition or other protection measures. Each future development project with the subwatershed is then subject to these technical criteria.

- Stream management strategies are then modified to include any management recommendations that may arise from larger scale planning efforts (e.g., at the scale of the watershed, subbasin or basin). For example, a subwatershed strategy might be amended to incorporate nutrient management objectives developed at the basin scale (e.g., Chesapeake Bay Nutrient Management) or address water use classifications for the stream designated by a State water quality agency.

- The last step in watershed–based zoning is the implementation of a long–term monitoring program to assess whether the stream management strategies are indeed achieving the stream quality goals set for each subwatershed. The purpose of the low cost monitoring program is to track the growth of impervious cover in each subwatershed using geographic information systems (GIS) and monitor the status of biological indicators within urban streams. (See Claytor and Ohrel 1995.)

Although many communities are experimenting with either impervious cover limits and comprehensive watershed studies, none have applied them together in a truly watershed–based zoning process. Watershed– based zoning has more benefits when compared to traditional zoning. For example, watershed–based zoning:

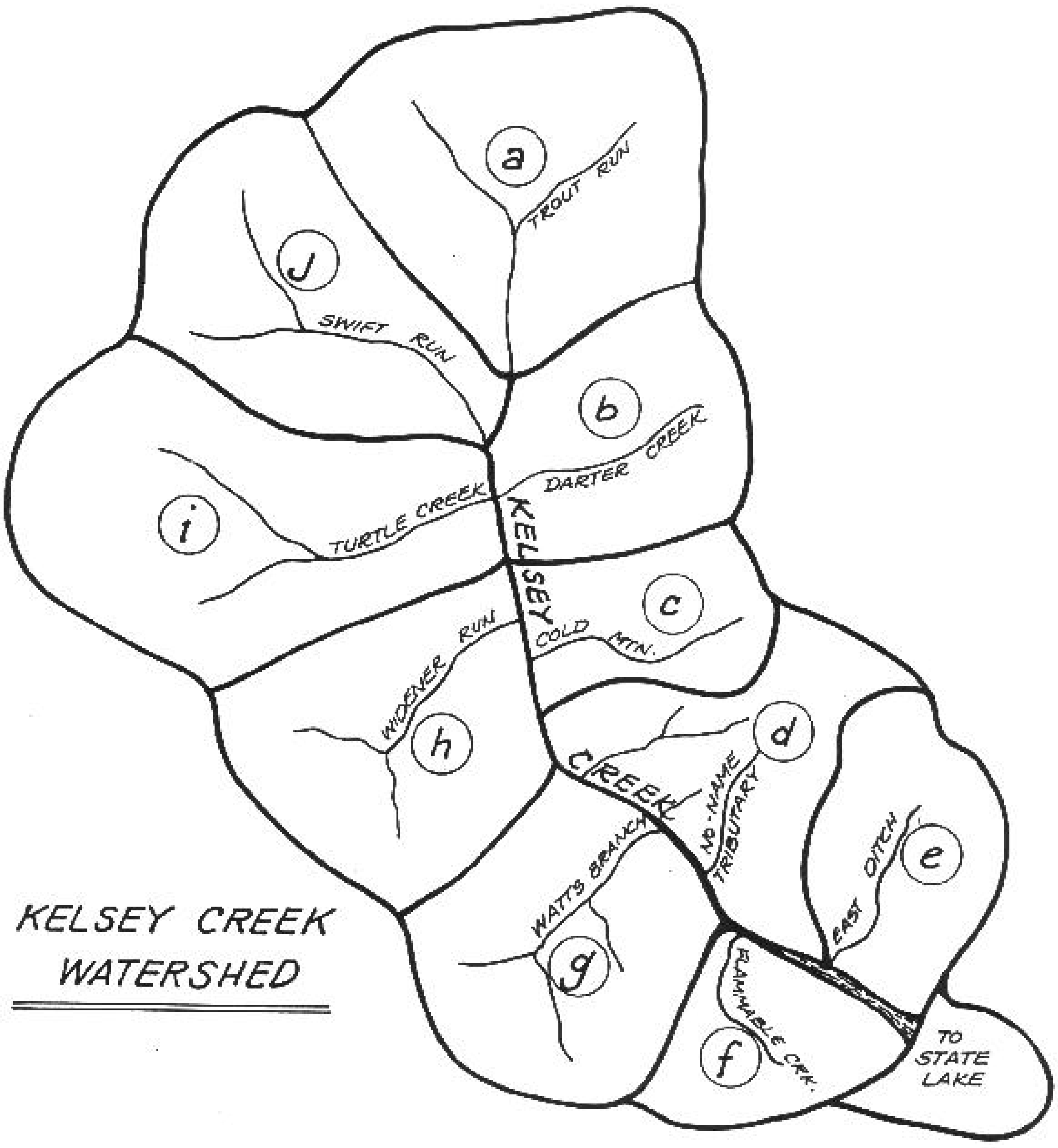
- Helps track the cumulative impact of urban development on aquatic systems.

- Provides a legally defensible and scientifically acceptable foundation for better land use decisions.
- Creates a quantitative measure (imperviousness) that can be used to monitor and enforce zoning actions at the site or the watershed scale.
- Acknowledges the primary importance of land use control to protect streams and guards against an over–reliance on structural BMPs.
- Recognizes that unique stream protection strategies must be specifically adapted for subwatersheds of different impervious cover.

Stream Protection Strategies Under Watershed–Based Zoning

Watershed–based zoning provides a useful framework to craft more effective stream protection strategies within individual subwatersheds. It begins with the notion that the amount of impervious cover largely determines the future quality of streams and therefore, the attainability of our stream protection goals. This in turn strongly influences the nature of the stream protection strategy for a given subwatershed, i.e., the choice of what land use controls, BMPs, streamside management, and other tools that

FIGURE 15: DESIGNATING AND MANAGING STREAMS AT THE SUBWATERSHED LEVEL



In this example, a community examines the effect of currect and future growth on each of its ten subwatersheds, and designs a unique stream protection strategy for each one

TABLE 9: EXAMPLE OF WATERSHED-BASED ZONING FOR KELSEY CREEK WATERSHED

ID No	Subwatershed Name	SUBWATERSHED IMPERVIOUS COVER			Subwatershed Classification	Stream Protection Goal or Technique
		Current Imp	Zoned Imp	Target Imp		(based on proximity to Imp. threshold and stream surveys)
A	Trout Run	4%	5%	5%	Sensitive	No water/sewer extension
B	Darter Creek	9%	15%	10%	Sensitive	Subwatershed Imp. Cap at 10% Incentives for Site I Reduction
C	Cold Mtn	9%	18%	15%	Degrading	Channel habitat protection
D	No Name Trib	45%	65%	none	NonSupporting	Attract Redevelopment and Greenways
E	East Ditch	28%	55%	none	NonSupporting	Widespread BMP Application
F	Flamable Ck	65%	70%	none	NonSupporting	Intensive Pollution Prevention
G	Watts Branch	30%	35%	30%	NonSupporting	Candidate for Subwatershed Restoration, Maintain Imp.
H	Widener Run	15%	18%	18%	Degrading	Infiltration/Filtering BMPs (No Ponds)
I	Turtle Creek	20%	28%	25%	Degrading	Maintain Existing Designation
J	Swift Run	6	8%	8%	Stressed	Wide Buffers and I Reduction

In this example, a community examines the effect of current and fugrowth on each of its ten subwatersheds, and designs a unique stream protection strategy for each one.

can be applied. Thus, in each subwatershed, a unique and specific protection strategy is crafted for the stream, depending on whether it falls into the sensitive, degraded or non– supporting category. Table 10 presents some ideas on how to craft an integrated stream protection strategy within the watershed– based zoning framework.

Land Use Controls

Land use controls are the fundamental element of any stream protection strategy. For sensitive subwatersheds, a watershed–wide limit of 10% impervious cover is imposed, while an upper limit of 25% is allowed for degrading subwatersheds. No upper limit for impervious cover is established for non–supporting streams; indeed, these subwatersheds are designated for future growth or redevelopment.

The watershed–wide limits on impervious cover are enforced through a combination of zoning and incentives for reducing impervious cover at individual development projects at the catchment level.

BMP Selection and Design Criteria

Perhaps the greatest difference between the three stream protection categories is the criteria used to select and design urban BMPs. For example, in sensitive subwatersheds the primary objectives are to maintain predevelopment hydrology, minimize stream warming, and reduce sediment loadings. The use of stormwater ponds or wetlands is highly restricted, and filtering systems (such as sand filters, swales and biofilters) that are located away from the stream network are preferred. In general, all BMPs are explicitly designed to minimize any secondary environmental impacts (wetland or forest conversion, stream warming, etc.).

A wider range of BMP options are allowed in degrading subwatersheds. The two main objective for BMPs are reliable pollutant removal and reduction in the frequency of bankfull and subbankfull floods, which are so destructive of stream habitat. Pond or wetland designs that provide for extended detention of stormwater runoff are a preferred option.

In non–supporting subwatersheds, the central stream protection objective is to reduce stormwater pollutant loads, with special emphasis on nutrients, carbon and metals. Pollution prevention programs are also an effective management option in non–supporting subwatersheds, as they can control the greater density of stormwater pollutant hotspots found in the developed landscape.

Streamside Management

The objectives of streamside management changes based on a stream's classification. In sensitive subwatersheds, the goal is to create wide stream valley parks to provide the greatest level of protection for the stream. Standard–sized stream buffers are used to protect streams in degrading subwatersheds. Lastly, buffers in non–supporting sub– watersheds are managed as greenways, with a fairly wide range of uses allowed within the buffer to attract residents to the stream and meet the diverse recreational needs of a denser population.

Monitoring

Unique techniques and metrics are used to determine whether stream protection objectives are being achieved, given its stream classification category. For example, monitoring in sensitive subwatersheds concentrates on the long–term trends in fish or aquatic insect diversity, or the status of a single indicator species (e.g., trout). Monitoring of degrading subwatersheds emphasizes the early detection of physical changes in stream habitat, and may utilize rapid stream assessment techniques that measure both physical and biological parameter. Lastly, monitoring efforts for non–supporting subwatersheds are more oriented to water

TABLE 10: STREAM PROTECTION STRATEGIES UNDER THE WATERSHED-BASED ZONING FRAMEWORK

Urban Stream Classification	**Sensitive 0-10% Imperv.**	**Degrading 11- 25% Imperv.**	**Non-Supporting 26 + % Imperv**
Stream Quality Goal	Preserve biodiversity and channel stability at predevelopment level	Limit degradation to stream quality	Minimize pollutant loads delivered to downstream waters
Land Use Controls	Watershed-wide limits on imperv. cover, restrictions on site imperv. cover.	Upper limit on watershed impervious cover.	No watershed imperv. limits.
BMP Selection Criteria	Maintain pre-dev. hydrology (ED or I). Minimize stream warming and sedimentation. Only off-stream ponds Preference for filtering systems	Maintain pre-dev. hydrology (ED). Maximize pollutant removal. Ponds/wetlands OK with some restrictions	Maximize pollutant removal and quantity control. Remove N,P and metals, toxics No restrictions on ponds and wetlands
Streamside Management	Stream valley buffers, few uses allowed	Stream buffers	Greenways
Monitoring	Biological indicators, including single-species (e.g. trout)	Biological and physical indicators	Water quality trends, BMP performance
Enforcement	GIS tracking of impervious cover	GIS, biomonitoring trends, BMP surveys	Simulation model, WQS standards
Development Rights	Transferred out	No transfers	Transferred in
Other Tools	Land acquisition, extraordinary E&S control, special review	Regional BMPs	Pollution prevention, Stormwater retrofits, illicit connections, restoration inventory

The precise impervious cover ranges shown in this example are illustrative and may shift slightly due to regional and climatic conditions or historical management of the stream channel (e.g., ditching).

quality, so as to detect changes in pollutant concentrations or loads delivered to downstream waters.

Enforcement

A key enforcement mechanism for both sensitive and degrading subwatersheds are aerial surveys that track growth of impervious cover over time (followed by GIS analysis and mapping). The maps are a useful tool to determine if watershed–wide impervious cover limits are being met.

Degrading streams have additional enforcement mechanisms beyond impervious cover tracking. These mechanisms are used to track the changes in stream degradation to determine if the upper limit of 25% impervious cover is adequate to protect key stream functions and quality. Thus, trends in key biological/physical stream monitoring variables are routinely analyzed. Another enforcement mechanism involves systematic evaluation of the longevity and performance of the BMPs installed.

Development Rights

Transferrable development rights (TDRs) can be used as a powerful incentive to protect green space in sensitive subwatersheds. Development rights of one parcel of land where growth is not desired (a "sending zone") are transferred to another parcel of land (a "receiving zone") where growth is encouraged at a higher density than would otherwise be possible (Coughlin 1991). TDRs have been used by many communities over the last decade to preserve open space or farmland, and should be easily adapted for the purposes of stream protection. Sensitive subwatersheds would constitute the sending zone, while non–supporting subwatersheds would be the receiving zone. Some useful guidance on how these innovative planning techniques can be implemented is found in NGMLP (1993).

Other tools and policies that can help support each stream protection strategy are described in Table 8.

Deriving a Local Impervious Cover/Stream Quality Relationship

While recent research on the links between imperviousness and stream quality are compelling, some communities may not feel that the research can support zoning and regulatory actions at the current time. One key reason is that the watershed imperviousness research has not yet been standardized. Different investigators, for example, have used different methods to define and measure imperviousness. Second, researchers have employed a wide number of techniques to measure stream quality characteristics that are not always comparable. Third, most of the studies have been confined to few ecoregions in the country. No research has been conducted in the Northeast, Southeast, Midwest and semi–arid regions of the West. Lastly, study has yet to systematically examine the effect of widespread application of BMPs on the impervious cover/stream quality relationship. BMPs could possibly shift some of the impervious cover thresholds that are used to classify urban streams.

TABLE 11: PROTOCOL TO DEFINE FUNCTIONAL RELATIONSHIPS BETWEEN WATERSHED IMPERVIOUSNESS AND STREAM QUALITY

General Study Design: A systematic evaluation of stream quality for a population of 20 to 50 small subwatersheds that have different levels of watershed imperviousness. Selected field measurements are collected to represent key hydrological, morphological, water quality, habitat and biodiversity variables within each defined subwatershed. The population of subwatershed data is then statistically analyzed to define functional relationships between stream quality and imperviousness.
Selecting Subwatersheds: drainage areas from 100 to 500 acres, known level of imperviousness and age, free of confounding sources (active construction, mining, agriculture, or point sources). select three random non-overlapping reaches (100 feet) for summer and winter sampling of selected variables in each of the five key variables groups shown below:
Defining Reference Streams: up to 5 non-urban streams in same geo-hydrological region, preferably fully forested, or at least full riparian forest coverage along same length. Free of confounding NPS sources, imperviousness less than 5%, natural channel and good habitat structure.
Basic Subwatershed Variables: watershed area, standard definition and method to calculate imperviousness, presence/absence of BMPs.
1. Hydrology Variables: summer dry weather flow, wetted perimeter, cross-sectional area of stream, peak annual storm flow (if gaged).
2. Channel Morphology Variables: channel alteration, height, angle and extent of bank erosion, substrate embeddedness, sediment deposition, substrate.
3. Water Quality Variables: summer water temperature, turbidity, total dissolved solids, substrate fouling index, wet weather bacteria, wet weather hydrocarbon.
4. Habitat Variables: pool- riffle ratio, pool frequency, depth and substrate, habitat complexity, instream cover, riffle substrate quality, riparian vegetative cover, riffle embeddeness
5. Ecological Variables: fish diversity, macroinvertebrate diversity, index of biological integrity, EPA Rapid Bioasessment Protocol, fish barriers, leaf pack processing rate.

Communities, however, can define the cover/quality relationship in a short time and at relatively low cost. A suggested protocol for conducting a watershed monitoring study is presented in Table 11. The protocol emphasizes comparative sampling of a large population (20–50) of urban subwatersheds of different increments of imperviousness. A rapid sampling program collects consistent data on hydrologic, morphologic, water quality, habitat and biodiversity variables within each subwatershed. For comparison purposes, undeveloped and undisturbed reference streams are also monitored. The sampling data are then statistically and graphically analyzed to determine the presence of imperviousness/stream quality relationships. The cost to conduct the subwatershed monitoring program can range from $100,000 to $300,000, roughly the cost of a BMP system for a large subdivision.

The protocol can be readily adapted to examine the impacts of BMPs in shifting the cover/quality relationship. This is done by dividing the population of subwatersheds into two groups—those that are effectively served by BMPs and those that are not.

Summary

Watershed–based zoning gives greater confidence that stream protection objectives can be met in the face of future development. It also forces local governments to make hard choices about which streams will be fully protected and which will become at least partially degraded. Some environmentalists and regulators will be justifiably concerned about the streams whose quality is purposely sacrificed under this scheme. The explicit stream quality decisions which are at the heart of watershed–based zoning, however, are preferable to the uniformed and random "non–decisions" that are made in the present zoning system.

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